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ON THE MONTICELLITE-LIKE MINERAL IN METEORITES, AND
ON OLDHAMITE AS A METEORIC CONSTITUENT*

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It may be remembered that in 1883 Tschermak¹ mentioned the occurrence in many chondritic meteorites of an almost colorless constituent occurring with very irregular outlines, in the groundmass, and exceeding in size the prevailing granules. These showed only traces of cleavages, were doubly refracting and optically biaxial though never showing good interference figures. The polarization colors were weak. It was found impossible to determine absolutely the mineral nature of the constituent, but it was suggested that it might be monticellite. Its presence was noted in the Alfianello, Mocs, Knyahinya, and Mezo Madaras stones. The occurrence in the Knyahinya stone was later figured by him on plate 14, figure 3, of his *Die Mikroskopische Beschaffenheit der Meteoriten*. Since Tschermak's writing the mineral has been noted by various authors. Lacroix² describes in some detail what is unquestionably the same mineral in the stone of St. Christophe la Chartreuse. He finds it possessing two easy but interrupted cleavages, cutting at an angle of about 60°, with a birefringence less than 0.003, which he notes is less than that of olivine and superior to that of feldspar, with which it is often found in contact. He also was unable to determine its exact nature optically, or to separate it by means of heavy solution, but noted that it could not be monticellite on account of its low birefringence. He further noted its occurrence in the meteorites of Chantonay, d'Aumale, de Barbotan, de Salles, de Berlanguillas, and Lancon. The present writer recognized the same mineral in sections of the meteorites from Rich Mountain, N. C.,³ and Felix, Alabama,⁴ and though recognizing its biaxial nature and weak birefringence was likewise unable to identify it absolutely. Still later, Borgström recognized it in the meteorite of St. Michel,⁵ and was able to determine the positive character of the acute bisectrix.

In connection with his work on the minor constituents of meteorites, the present writer had opportunity for examining numerous occurrences of the mineral, and it was decided if possible to determine its nature or at least to carry a knowledge of its properties one step farther. Unable by the means at his command to fully satisfy himself regarding all its

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optical properties further than given in the paper referred to above, sections of both the Alfianello and Rich Mountain stones were submitted to Dr. F. E. Wright of the Geophysical Laboratory, who reported the mineral to be weakly birefracting with interference colors not exceeding gray white of the first order, and the refractive indices of which were $\alpha = 1.623 \pm 0.002$ and $\gamma = 1.627 \pm 0.002$, the birefringence being less than 0.005. He also verified previous determinations of its biaxial and doubtfully positive character. With these additional data at hand reference was made to E. S. Larsen's tables,⁶ where it was found that the only known mineral possessing the properties found by the various observers was the phosphate *francolite*, which is reported, however, as optically negative. Nevertheless, with this much for a guide, an attempt was then made at ascertaining its chemical nature. The small size of the particles and their sporadic occurrence rendered it impossible to isolate them either by heavy solution or by an electro-magnet. Recourse was then made to micro-chemical methods. After repeated trials, a small particle, less than 0.5 mm. in diameter, was removed from an uncovered section of the Alfianello stone, and transferred to a clean slide where it was covered with a drop of strong hydrochloric acid and allowed to stand over night, during which time the acid evaporated to dryness. On taking it up again in a fresh drop of acid the mineral was found to have been strongly attacked though not completely dissolved. A drop of the solution was then transferred to still another slide and placed in contact with a drop of sulphuric acid. Abundant acicular and plumose crystals of gypsum shortly began to make their appearance around the margin of the drop. The liquid remaining on the first slide was then evaporated to dryness over an alcohol lamp and the residue taken up with nitric acid, a drop of ammonium molybdate solution added, and the slide slightly warmed on the steam radiator for a few moments, when abundant characteristic globules of the phospho-molybdate of ammonium separated out. As checks upon this, independent tests were made in slides from the Alfianello, Dhurmsala, Felix, Mocs, and Rich Mountain, meteorites by painting around the mineral with vaseline and treating the exposed portion with a drop of nitric acid. The mineral was found to be completely and easily soluble in this acid and in all cases results confirmatory of the first were obtained. It may be added that the solution in nitric acid goes on so rapidly that its progress may readily be observed under the microscope. In making this test, nitric acid has the advantage in that it does not so readily attack the olivine and there is hence no trouble from the obscuring reactions by gelatinous silica. The tests for other constituents, such as alumina,

yielded no satisfactory returns. As a last resort a 12-gram fragment of the Alfianello stone was submitted to Dr. Whitfield with the request that it be pulverized, and, after removal of the metallic portion, boiled in water to remove any possible oldhamite or its alteration products, and the residue then boiled in dilute hydrochloric acid. Disregarding as a matter of necessity the iron and magnesia which might come from the olivine, the results obtained were as follows: The water solution yielded 0.03% CaO and 0.013% S, the equivalent of 0.030% CaS, or oldhamite. The acid solution yielded 0.344% CaO and 0.08% P_2O_5 , with traces of alumina.

Satisfactory results from such tests could scarcely be anticipated but are nevertheless not without interest. It will be recalled that the ratio of CaO to P_2O_5 in francolite as given by Schaller⁷ is 10 to 3. The results obtained by Whitfield by the method described were 9 to 2.

The accompanying figures, drawn free hand, directly from the thin sections, will serve to give an idea of the general appearance and optical properties of the mineral. No attempt has been made to outline other of the constituents excepting where noted as enclosures. The actual size of the largest forms, as those of Alfianello and Rich Mountain (figs. 1 and 2), is not above 0.5 mm. in diameter. In figure 1, from a slide of the Alfianello stone, the mineral in question, left colorless and unshaded, is traversed by wavy cracks or cleavage lines extending from the upper right to the lower left. The dotted areas are olivine and those with broken parallel lines at the right are enstatite. The completely black are metal and metallic sulphide. In the upper portion the mineral reaches its maximum extinction in the position indicated by the cross. In the lower right, which remains almost completely dark during an entire revolution of the stage, there appears an indistinct, slightly curved black bar, indicating the emergence of an optic axis of a biaxial mineral.

Figure 2, from a slide of the Rich Mountain stone, shows likewise a characteristic occurrence, with near the center an enclosure of olivine and other scattered enclosures of the same mineral and metallic particles. The entire area extinguishes as a unit and in the position indicated by the cross, though the lower portion shows indications of two cleavages and an indistinct black brush sweeps across the field as the stage is revolved between crossed nicols with the ocular removed.

Figures 3 and 4 show the same mineral in the Pultusk and Dhurm-sala stones, respectively. The position of maximum extinction is again shown by the black cross. In figure 4, which extinguishes as a unit, two easy but interrupted cleavages are very evident at the left and bot-

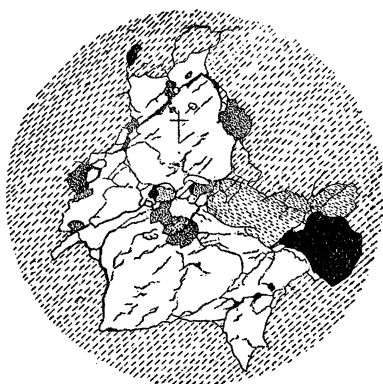


Fig. 1

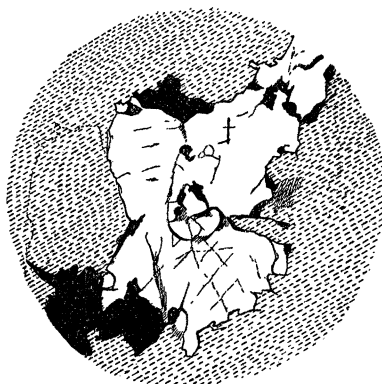


Fig. 2

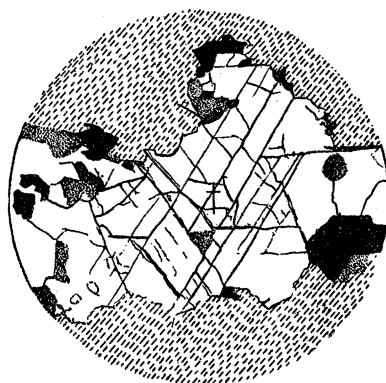


Fig. 5

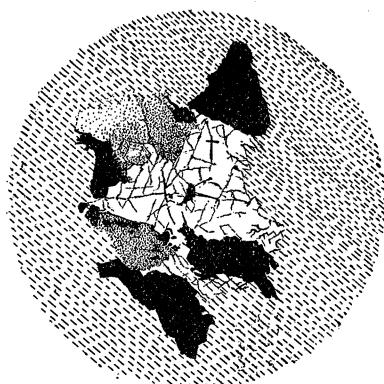


Fig. 3

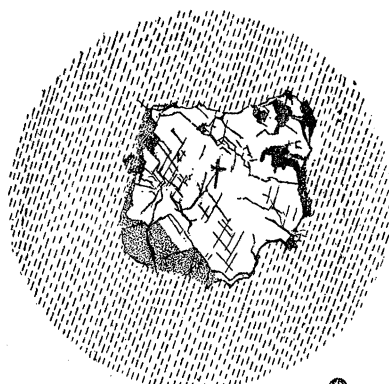


Fig. 4

tom of the section. No satisfactory interference figure is obtainable from this section, though a very indistinct dark brush sweeping across the field indicates that the plane of the optic axes cuts the obtuse angle of cleavage.

In figure 5 is shown an occurrence in the Mocs stone concerning which there was considerable doubt, not merely on account of the perfection of the cleavage but from the fact that it showed an indistinct interference figure in which the axial angle was so small that it was at first thought to be uniaxial: it was, moreover, optically negative, and more nearly resembles normal apatite than do the other occurrences under discussion. To settle the matter the cover was removed from the slide and the mineral treated with a drop of nitric acid as in previous cases. Within an hour from the time the drop was applied the mineral was entirely eaten out and the solution, as before, yielded lime and phosphoric acid, with the proper reagents.

The accumulated determinative characteristics of the doubtful mineral so far as made out by the various workers are then as follows:

Colorless, with but few inclosures, two cleavages, imperfect and interrupted, cutting at an acute angle of 60° ; optically biaxial and positive (?), with large $2E$; birefringence weak, less than 0.005, refractive indices, as determined by Dr. Wright, $\alpha = 1.623 \pm 0.002$ and $\gamma = 1.627 \pm 0.002$; no pleochroism, and often with undulatory extinction; polarization in light and dark colors and at times almost completely dark during a revolution of the stage between cross nicols; easily soluble in cold nitric acid, giving solutions reacting for lime and phosphoric acid; very brittle and occurrence sporadic.

There is apparently no question then but that we have a heretofore unrecognized form of mineral phosphate as a fairly common constituent of meteoric stones. From normal apatite it differs in its low birefringence as well as cleavage and general optical characters. From francolite it would appear to differ in that so far as determined it is optically positive, while the latter is negative. Just how much weight is to be attached to this last characteristic, is yet to be determined. One has a natural hesitation in relegating it to francolite for genetic reasons, since francolite, so far as known, is a secondary mineral and a deposit from aqueous solution. It is to be noted, however, that the mineral I have been describing occurs with outlines suggestive of its secondary origin and filling drusy cavities formed at the time of the original consolidation of the stone in which it occurs. Whether secondary or not, as the term is usually employed, it is certainly a product of the latest period of crystallization. Until the material can be found in such quan-

tity as to be available for chemical analysis, apparently this is the best that can be done. Attention may, however, be called to the fact that phosphorous in the form of apatite has thus far been definitely recognized in meteorites only by Berwerth,⁸ although a small amount of phosphorous is almost invariably reported either as P or P_2O_5 from the soluble (silicate) portion of the stony meteorites. It would seem probable, therefore, that this soluble salt is not in the form of apatite but that rather it owes its presence to the monticellite-like mineral which is now relegated doubtfully to the species francolite.

On the assumption that the doubtfully monticellite-like mineral referred to by the various workers is in all cases to be relegated to the same species, it has now been recognized in the stones listed below.

Alfanello,	Chantonnay,	Lancon,	Rich Mountain,
Aumale,	Dhumsala,	Mezo Madaras,	Saint Christophe,
Barbotan,	Felix,	Mocs,	Saint Michel,
Berlanguillas,	Knyahinya,	Pultusk,	Salles.

OLDHAMITE AS A METEORIC CONSTITUENT

The presence of the calcium sulphide oldhamite in a meteorite was first made known by Maskelyne who found it in granules macroscopically developed in the Busti stone.⁹ He also noted its probable presence in that of Bishopville, and suggested an even wider distribution. Since Maskelyne's writing but few new occurrences have been noted, though its probable presence has been more than once suggested. The present writer found a lime salt soluble in water in the Morristown meteorite which he surmised might be gypsum, resulting from the alteration of the sulphide.¹⁰ He also found abundant chemical evidence of its one-time presence in the stone of Cullison,¹¹ and was able to verify Lacroix's microscopic determination of its presence in the Indarch stone.¹² Borgström has also shown its presence in the stone from Hvittis,¹³ Cohen in that of St. Marks,¹⁴ and Tassin by chemical tests has pointed out its probable occurrence in that of Allegan.¹⁵

These facts, considered in connection with my work on the minor constituents of meteorites, have led me to make a most careful search for the mineral, but with the exception of that of Indarch none of the stones examined have yielded absolute ocular proof of its occurrence. The known solubility of the mineral in water has, however, afforded opportunity for a safe presumption regarding its presence or absence.

Quantities of a gram or more from each of the stones listed below were finely pulverized and boiled for an hour or so in distilled water, the solutions then filtered and tested for lime with ammonium oxalate.

In alphabetical order the stones tested are as follows:

Alfanello, positive lime reaction	Holbrook, positive lime reaction
Beaver Creek, negative lime reaction	Homestead, positive lime reaction
Bishopville, positive lime reaction	Knyahinya, negative lime reaction
Cullison, positive lime reaction	L'Aigle, positive lime reaction
Dhurmsala, positive lime reaction	Mocs, positive lime reaction
Dores dos Campos, positive lime reaction	Monroe, negative lime reaction
Estherville, positive lime reaction	New Concord, doubtful lime reaction
Farmington, faint positive lime reaction	Parnallee, faint positive lime reaction
Fayette, positive lime reaction	Pultusk, positive lime reaction
Felix, positive lime reaction	Quenggouk, positive lime reaction
Forest City, positive lime reaction	Tennasilm, positive lime reaction
Hessle, faint positive lime reaction	

The mere presence of a soluble calcium compound does not necessarily prove the presence of oldhamite, but in cases where the boiling is accompanied by a liberation of H_2S , it would seem safe to assume its presence in this form, and in the cases of the stones of Alfanello, Bishopville, and Indarch we have been able from the lime in the water solution to calculate its approximate percentage amount.

That the mineral occurs more or less sporadically is suggested by Maskelyne's figure and description of the Busti stone, and has been demonstrated by our own researches, certain individuals from the Pultusk fall giving abundant indications of its presence, while others gave no sign. It is evident, however, that the mineral is a common and widespread constituent, and the examination of no stone meteorite should be regarded as complete unless it has been sought for by both optical and chemical means. A failure to find it in thin sections may be due to the breaking out of the granules in the process of grinding, or more likely, particularly in the case of stones that have lain long in the ground, to its having undergone alteration into an earthy, gypseous, and quite unrecognizable product.

¹ *Sitz. Wien. Akad.*, 88, No. 1, p. 355 (1883).

² *Bull. Soc. Sci. Nat. Ouest*, ser. 2, 6, 81-112 (1906).

³ *Proc. U. S. Nat. Mus.*, 32, 243 (1907).

⁴ *Ibid.*, 24, 196 (1901).

⁵ *Bull. de la Com. Geol. de Finlande*, No. 34, 1912, p. 43.

⁶ *Indices of Refraction of Minerals*, in MS.

⁷ *Bulletin* 509, *U. S. Geol. Survey*, p. 599.

⁸ *Min. u. Pet. Mittheil.*, 25, 188 (1906).

⁹ *Phil. Trans. R. Soc. London*, 160, 189-214 (1870).

¹⁰ *Amer. J. Sci.*, 11, 149 (1896).

¹¹ *Proc. U. S. Nat. Mus.*, 44, 330 (1913).

¹² *Proc. U. S. Nat. Mus.*, 1915.

¹³ *Die Meteoriten von Hvitits in Marjalahti*, 1903.

¹⁴ *Ann. S. African Mus.*, 5, 1-16 (1906).

¹⁵ *Proc. U. S. Nat. Mus.*, 34, 433 (1908).